

Dijet Production at Low Q^2 *

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Triple differential dijet cross-sections in $e^\pm p$ interactions measured with the H1 detector at HERA are presented. The data are compared to Monte Carlo simulations based on the DGLAP and CCFM parton evolution schemes. Effects of longitudinally polarized virtual photons are investigated.

1. Dijet Production at HERA

The production of dijet events at HERA is dominated by processes in which a virtual photon, coupling to the electron, interacts with a parton in the proton. In the region of photon virtuality $Q^2 \gg \Lambda_{QCD}^2$, hard collisions of the photons do not necessitate the introduction of the concept of the resolved photon (as for the real photon) and the process can in principle be described by the direct photon contribution alone.

The analysis presented here explores the region $\Lambda_{QCD}^2 \ll Q^2 \lesssim E_t^2$, where different theoretical approaches can be used to take into account higher order corrections – either next-to-leading order (NLO) calculations, k_t unordered initial QCD cascades, or additional interactions with resolved photons. Comparisons with NLO predictions are likely to become possible in the future. In more detail, the present measurements are compared with the following models:

a) LO direct and resolved interactions based on the DGLAP evolution equations and parton showers. The effects of transversally (γ_T^*) and also longitudinally (γ_L^*) polarized resolved photon interactions are studied [1, 2, 3]. The cross section for longitudinal photons vanishes for $Q^2 = 0$ due to gauge invariance. On the other hand, the concept of a resolved photon breaks down for $Q^2 > E_t^2$. Therefore the most promising region in

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which to search for the γ_L^* resolved processes is $\Lambda_{QCD}^2 < Q^2 \ll E_t^2$, which is often the case in the present analysis. The main difference between γ_L^* and γ_T^* induced interactions arises from the y dependence of the respective fluxes:

$$f_{\gamma^T/e}(y, Q^2) = \frac{\alpha}{2\pi} \left[\frac{2(1-y) + y^2}{y} \frac{1}{Q^2} - \frac{2m_e^2 y}{Q^4} \right] \quad (1)$$

$$f_{\gamma^L/e}(y, Q^2) = \frac{\alpha}{2\pi} \left[\frac{2(1-y)}{y} \frac{1}{Q^2} \right] \quad (2)$$

While for $y \rightarrow 0$, both transverse and longitudinal fluxes are approximately same, the longitudinal flux vanishes for $y \rightarrow 1$. Also the dependence of the point-like ¹ (i.e. perturbatively calculable) parts of the photon parton distribution functions (PDF) on Q^2 and E_t^2 differs – while the γ_T^* PDF are proportional to $\ln(E_t^2/Q^2)$, the γ_L^* PDF do not, in the first approximation, depend on either E_t^2 or Q^2 [2].

b) k_t unordered initial QCD cascades accompanying the hard process are present for example in BFKL or CCFM evolution. These evolution schemes can lead to final states in which the partons with the largest k_t may come from the cascade, and not, as in DGLAP evolution, from the hard subprocess. Such events may have a similar topology to that for the resolved interactions in the DGLAP approximation. This possibility is investigated using the CASCADE 1.0 generator [5, 6, 7] based on the CCFM evolution equations.

2. Measurement of Dijet Cross-Section

The measurement was done with 16.3 pb^{-1} of data collected in 1999, when the electron-proton center-of-mass energy \sqrt{s} reached 318 GeV. The analysis was performed in γ^* -proton center-of-mass system and jets were found using the k_t longitudinally invariant jet algorithm. The phase space is defined by the photon virtuality: $2 \text{ GeV}^2 < Q^2 < 80 \text{ GeV}^2$, the electron inelasticity: $0.1 < y < 0.85$, the transverse energy of two leading jets: $E_t^{jet1,2} > 5 \text{ GeV}$, $\bar{E}_t = (E_t^{jet1} + E_t^{jet2})/2 > 6 \text{ GeV}$ and the pseudorapidity of the two leading jets: $-2.5 < \eta^{jet1,2} < 0$.

The measured data are corrected for detector effects using the Bayesian unfolding method. The largest source of systematic errors arises from the model dependence of the detector correction, and from the main calorimeter calibration uncertainty.

¹ The perturbatively non-calculable hadron-like part of the photon PDF becomes negligible in our kinematical region with respect to the point-like one, as has been demonstrated in [4].

3. Results and Discussion

The corrected triple-differential dijet cross-section measured as a function of Q^2 , \overline{E}_t^2 and x_γ is shown in Fig. 1. A prediction of HERWIG [8] with the SaS1D parameterization of the γ_T^* PDF, as well as the pure direct contribution is compared to the data.

In general, HERWIG 5.9 and RAPGAP 2.8 [9] tend to underestimate the measured cross-section. The decrease of the resolved contribution at high \overline{E}_t^2 is of kinematic origin, due to the limited phase space at low x_γ . The direct contributions almost describe the data in the highest Q^2 bin, while a clear need for resolved processes is observed for $Q^2 \ll \overline{E}_t^2$.

In the highest Q^2 range ($25 < Q^2 < 80 \text{ GeV}^2$) and $x_\gamma < 0.75$, the HERWIG direct contribution almost describes the data in the lowest \overline{E}_t^2 bin, but is significantly below it in the highest \overline{E}_t^2 bin. This indicates that the relevance of the resolved photon contribution is governed by the ratio \overline{E}_t^2/Q^2 , rather than by Q^2 itself.

Standard HERWIG with direct and γ_T^* resolved contributions underestimates the data. The description is improved by adding γ_L^* resolved photon interactions, which is done using a slightly modified version of HERWIG with the longitudinal photon flux according to eq. (2) and a recent γ_L^* PDF parameterization [3]. As demonstrated in Fig. 1, the γ_L^* resolved contribution is significant, and brings HERWIG closer to the measurement.

On the other hand, a simple enhancement of the PDF of the γ_T^* in the resolved contribution could lead to a similar prediction as the introduction of resolved γ_L^* . To distinguish between a non-optimal choice of γ_T^* PDF and the need for resolved γ_L^* , the dijet cross-section has also been studied as a function of Q^2 , x_γ and y , which is shown in Fig. 2. HERWIG is below the data. The discrepancy becomes smaller if the resolved γ_L^* is added. According to eq. (1-2), the slope of inelasticity y of the HERWIG prediction in the region of $x_\gamma < 0.75$, depends significantly on whether γ_L^* processes are included or not. Unlike a pure enhancement of γ_T^* PDF, which would not change the slope of the y distribution, addition of γ_L^* brings the y dependence of HERWIG much closer to the measurement.

As motivated in Section 1, the measured cross-sections are also compared to a prediction of the CASCADE MC program based on the CCFM evolution scheme. This theoretical approach does not involve the concept of virtual photon structure and employs much fewer parameters for tuning than the usual DGLAP-based MC programs. CASCADE describes the data reasonably but not perfectly. In particular, the Q^2 dependence at low x_γ is poorly described.

As indicated by Fig. 2, the y dependence of the dijet cross-section is better described by CASCADE than by HERWIG without the γ_L^* resolved

process, since photon polarization states are correctly treated in CASCADE for all virtualities (only direct photon interactions are considered).

4. Conclusions

The importance of γ_T^* resolved photon interactions within the DGLAP evolution scheme at leading order is clearly demonstrated in the region where $\overline{E}_t^2 > Q^2$, even at rather high Q^2 . Additional γ_L^* resolved photon contributions further improve the agreement of HERWIG with the measured data.

Exploring the CCFM approach, the MC program CASCADE does not reproduce the data perfectly, the main discrepancy is observed in the Q^2 dependence at low x_γ . On the other hand, the x_γ dependence in CASCADE is comparable to the sum of the direct and resolved contributions in DGLAP-based MC programs, showing that non k_t ordered parton cascades can successfully produce the same observables as resolved virtual photons in the LO DGLAP evolution scheme.

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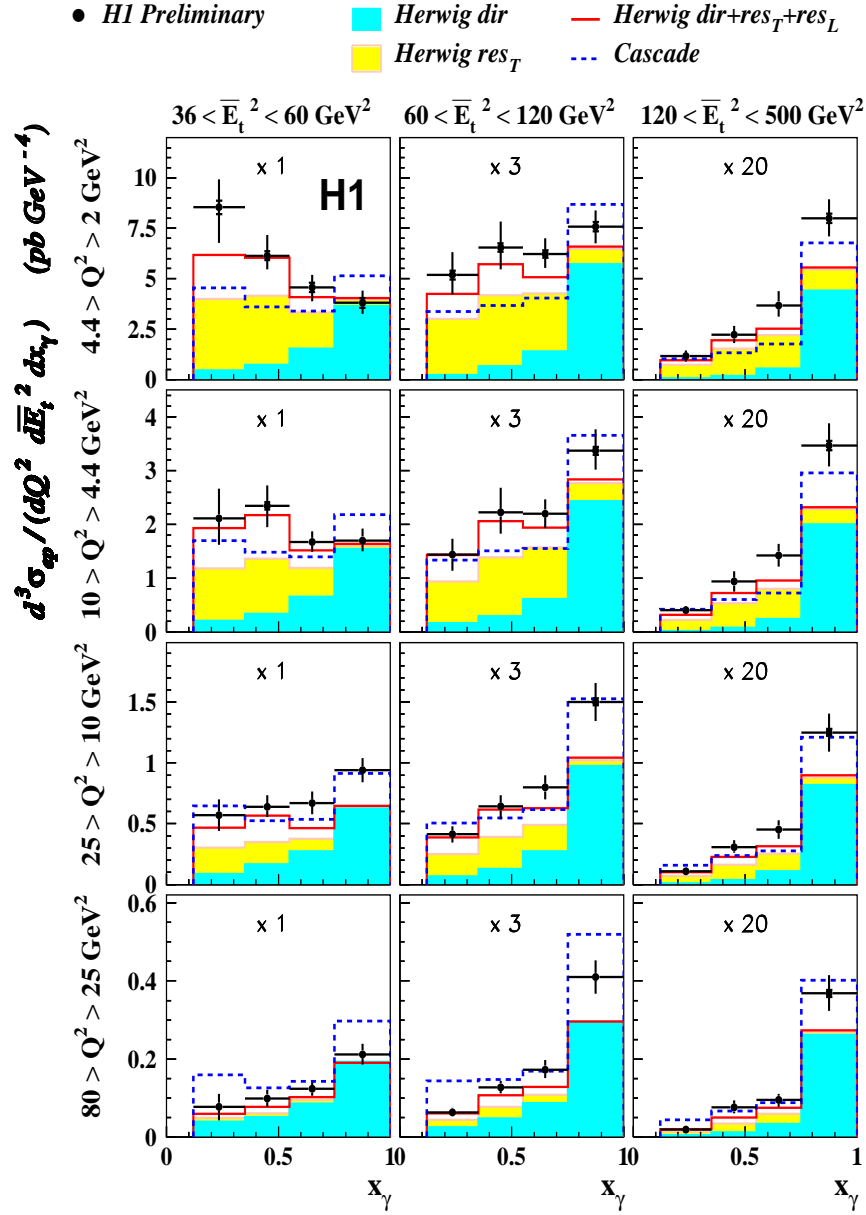


Fig.1. Triple differential dijet cross-section $d^3\sigma_{ep}/dQ^2 d\bar{E}_t^2 dx_\gamma$ for the H1 data depicted by points is compared to predictions of the HERWIG and CASCADE MC programs.

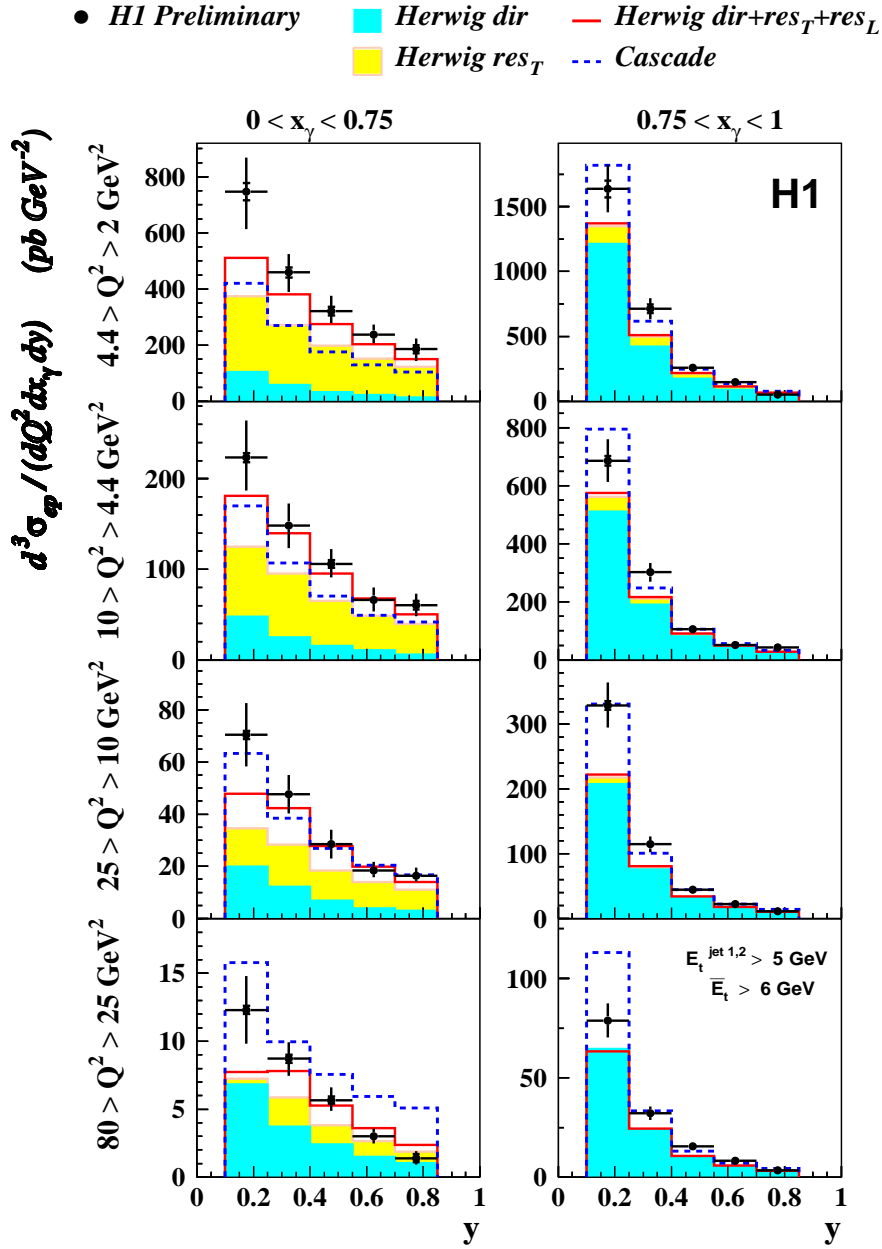


Fig. 2. Triple differential dijet cross-section $d^3\sigma_{ep}/dQ^2 dx_\gamma dy$.